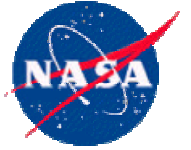


Mars Tumbleweed

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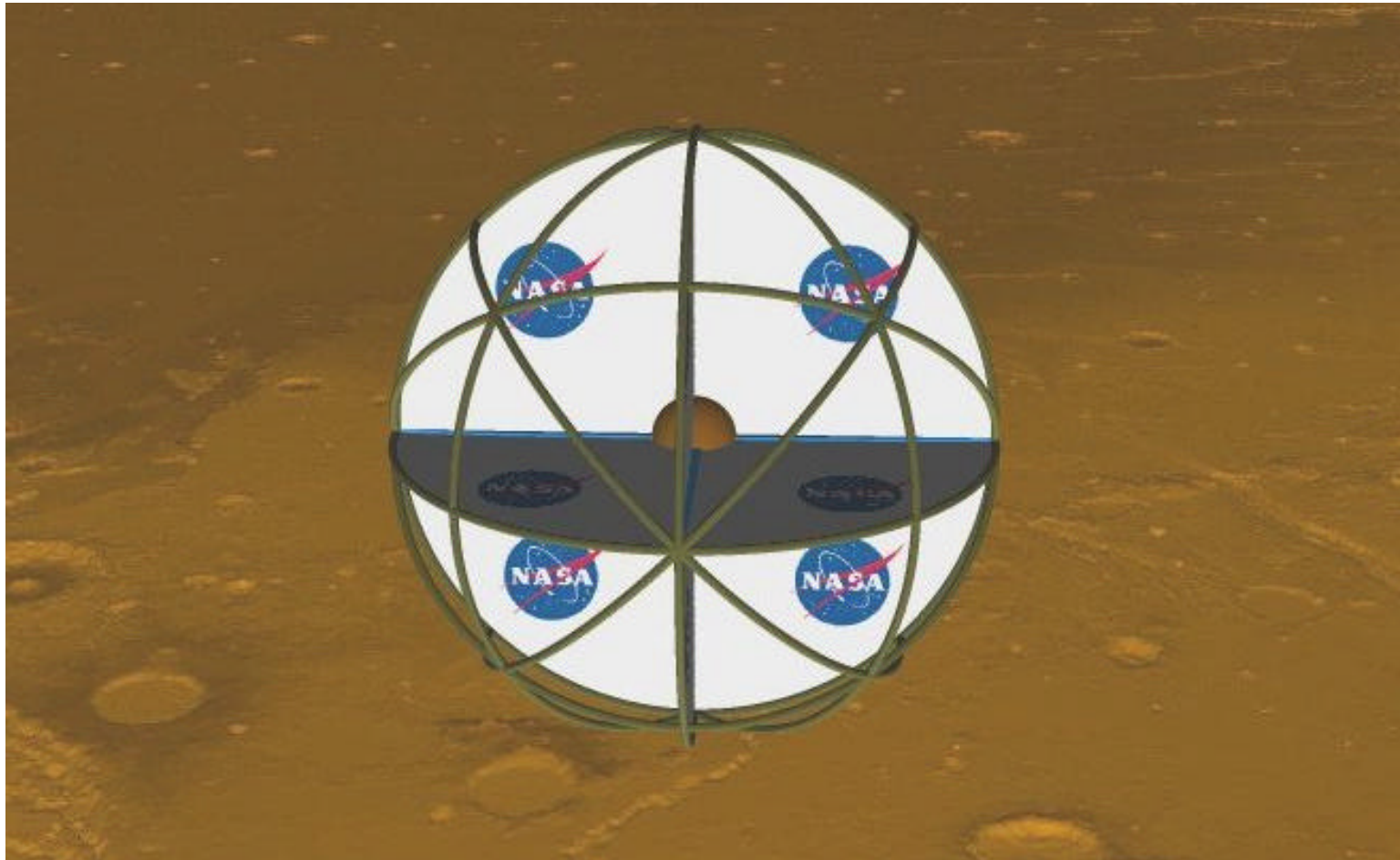
A New Way to Explore Mars

H. C. Hanrahan*, D. A. Minton**, F. R. DeJarnette**, I. A. Camelier*** & M. H. Fleming**

*Carnegie Middle School & **NC State University, Raleigh, NC, USA ; ***Univ. da Beira Interior, Portugal

6-9 October 2003, Lisbon Portugal

Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science Workshop



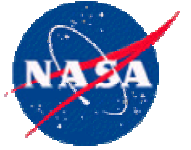
Mars Tumbleweed



Overview

- Why study Mars?
- What is a Mars Tumbleweed?
- Mars Tumbleweed Design Process
- The Tumbleweed Earth Demonstrator (TED)
- TED Systems Overview
- Manufacturing of TED & Operations
Testing of TED

Mars Tumbleweed



Why study the planet Mars?



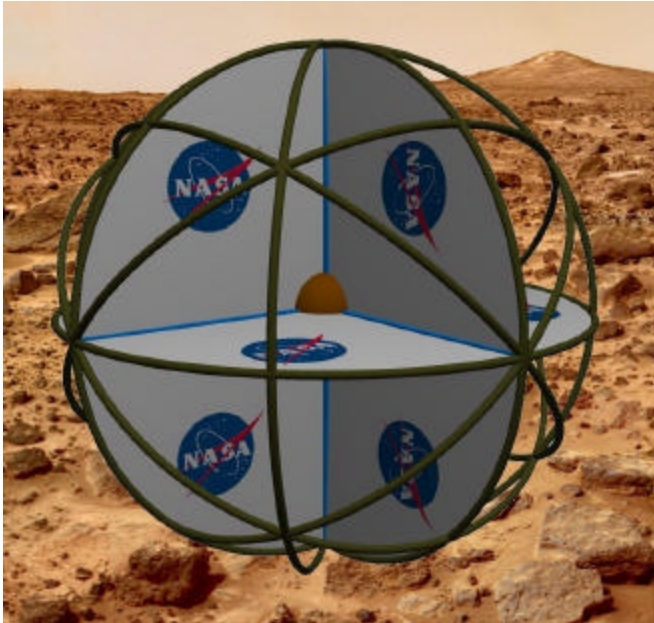
- 🌐 To learn more about Mars
- 🌐 To learn more about Earth and life here
- 🌐 To pave the way for future exploration, including human exploration and settlement

Image courtesy JPL

Mars Tumbleweed



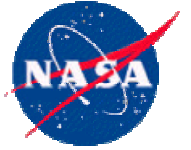
What is a Mars Tumbleweed?



Background image courtesy JPL

- Exploration of Mars using *in-situ resource utilization*
- Takes advantage of the Martian Winds as a propulsive resource
- Travels uncontrolled across a relatively large region taking data at multiple locations

Mars Tumbleweed



Mars Tumbleweed vs. traditional Mars rovers



Image courtesy JPL

- ❁ Requires no advanced AI guidance and hazard avoidance systems
- ❁ Can operate over scientifically interesting but hazardous terrain
- ❁ No moving parts
- ❁ Traditional rovers have limited range and require power to move

Mars Tumbleweed

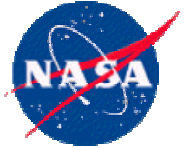
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Background

- 🌐 NASA Langley Research Center (LaRC) -
The Spacecraft and Sensors Branch
(SSB) Mars Tumbleweed Project
 - ▶ Principle Investigators: Jeff Antol & Greg Hajos.
- 🌐 Funding provided to NCSU through
NASA LaRC SSB and the NC Space
Grant Consortium

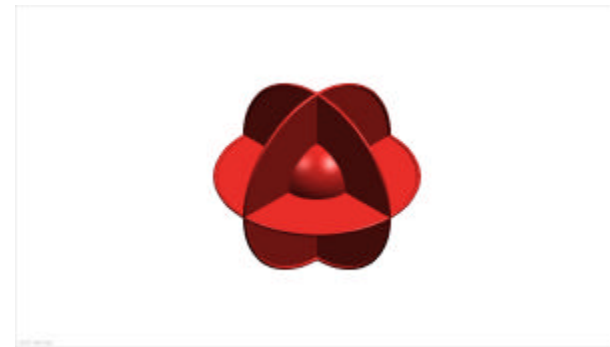
Mars Tumbleweed



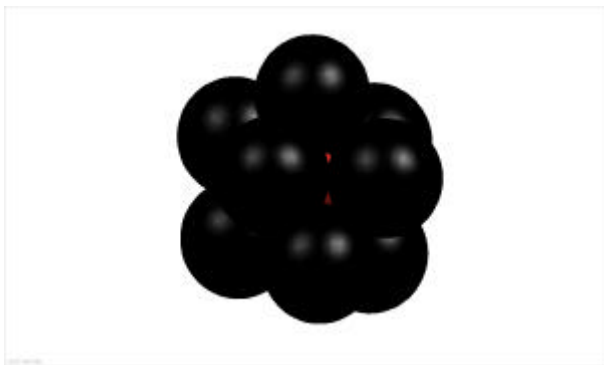
Choosing the Tumbleweed Shape



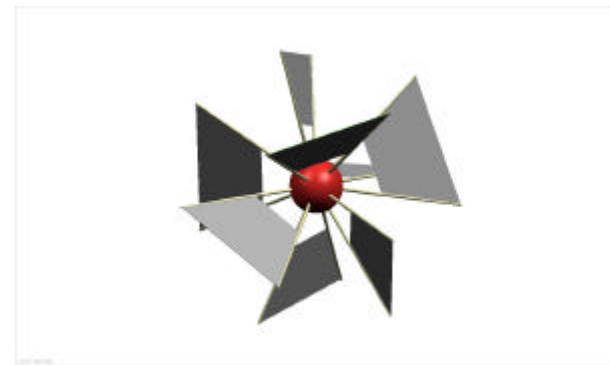
Tumblecup



Box Kite

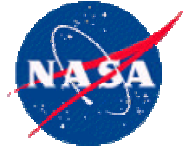


Wedges



Dandelion

Mars Tumbleweed



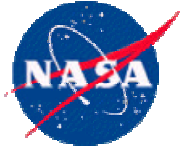
Figures of Merit – Drag

- Reynolds number matched to Mars conditions
 - Re = 50,000 – 110,000 based on 6m spherical Tumbleweed in winds of 7-15 m/s
 - 20-23 cm diameter models used in NCSU Subsonic wind tunnel at 3.8-8.3 m/s wind speed

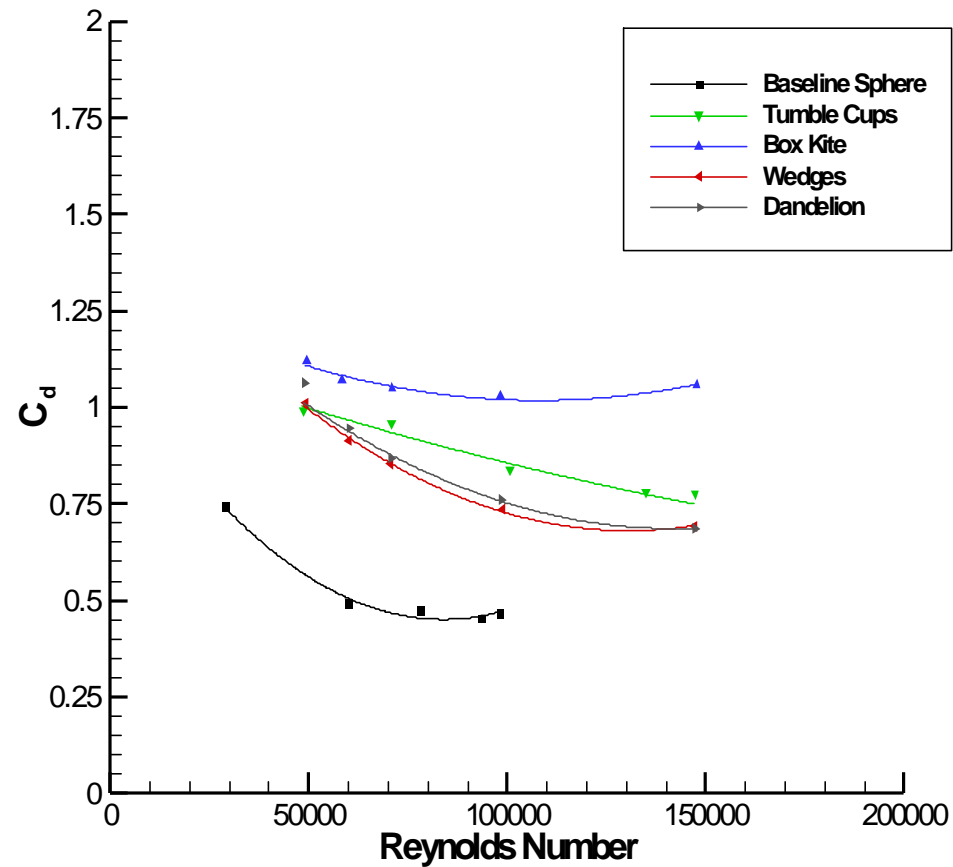
Average of Data from Mars Pathfinder

Gas	Pressure (Pa)	Temperature (K)	Density (kg/m ³)	Dynamic Viscosity (Pa-s)
CO ₂	680	250	0.0142	0.000012

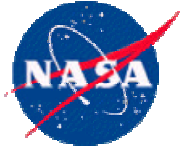
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Figures of Merit – Drag



Mars Tumbleweed

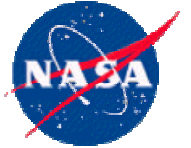


Figures of Merit

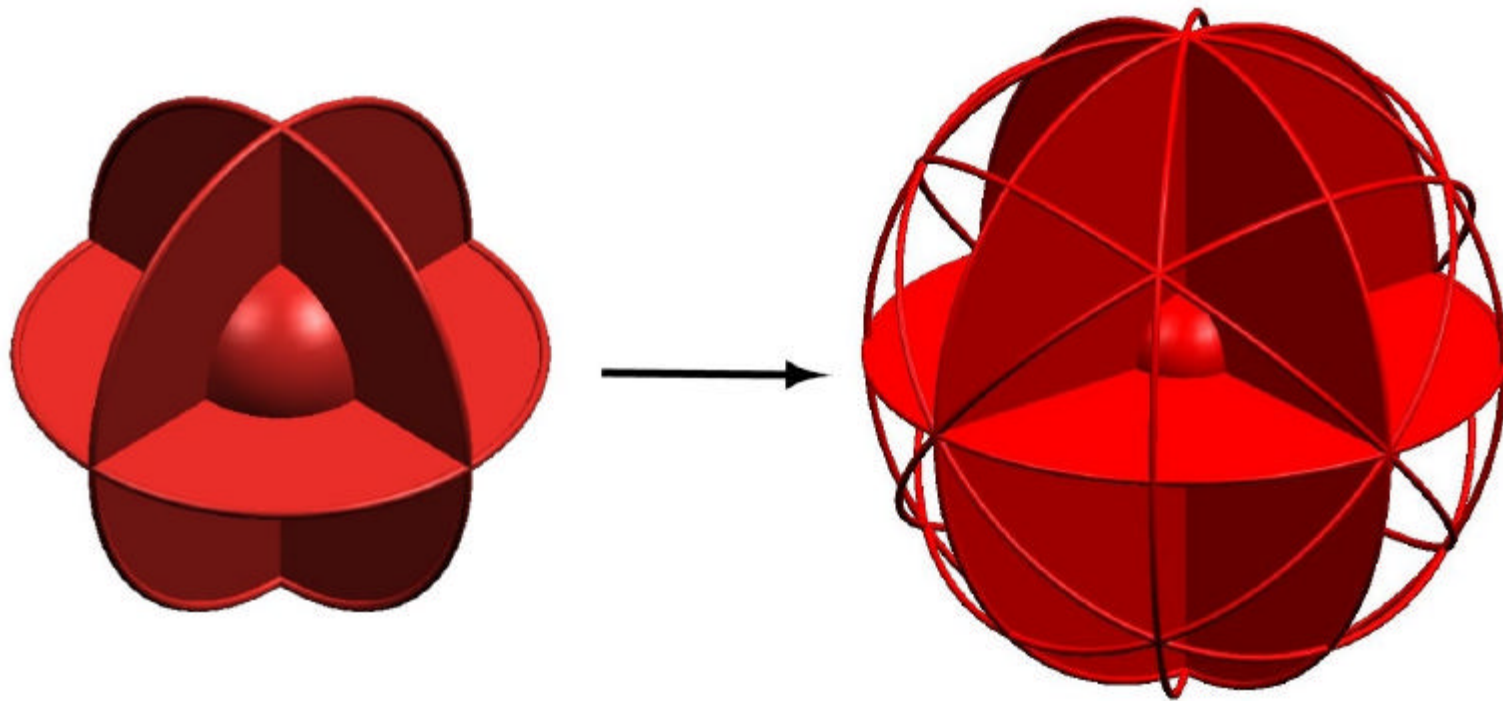
<i>Name and score</i>	<i>Drag</i>	<i>Major Parts</i>	<i>Mass</i>
Tumble cups	6.70	8.78	1.19
16.67			
Box Kite	10.00	10.00	3.54
23.54			
Balloons	6.23	10.00	3.03
19.27			
Dandelion	6.63	6.72	10.00
23.36			

Mars Tumbleweed

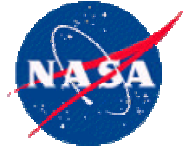
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Modified Box-kite



Mars Tumbleweed



Mars Tumbleweed Mission Sequence: Deployment

- Entry into the Martian Atmosphere
- Parachute descent and Tumbleweed Inflation
- Hot gas rigidization and impact with ground at terminal velocity ~ 11 m/s



Mars Tumbleweed



Materials

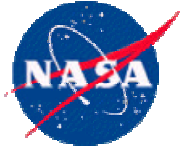
Carbon/Aramid Hybrid

- ▶ Lightweight
- ▶ High Strength
- ▶ High Impact Resistance

Kapton

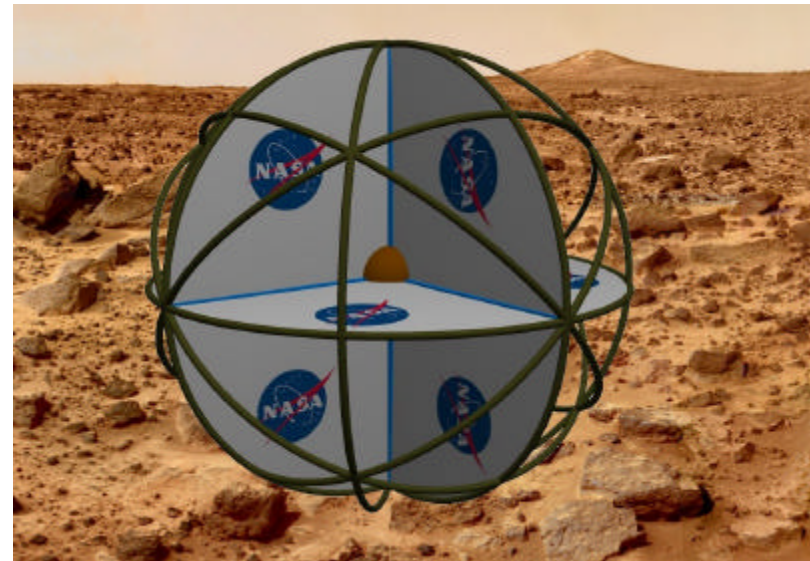
Heat Cured Epoxy

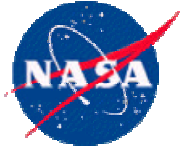
Mars Tumbleweed



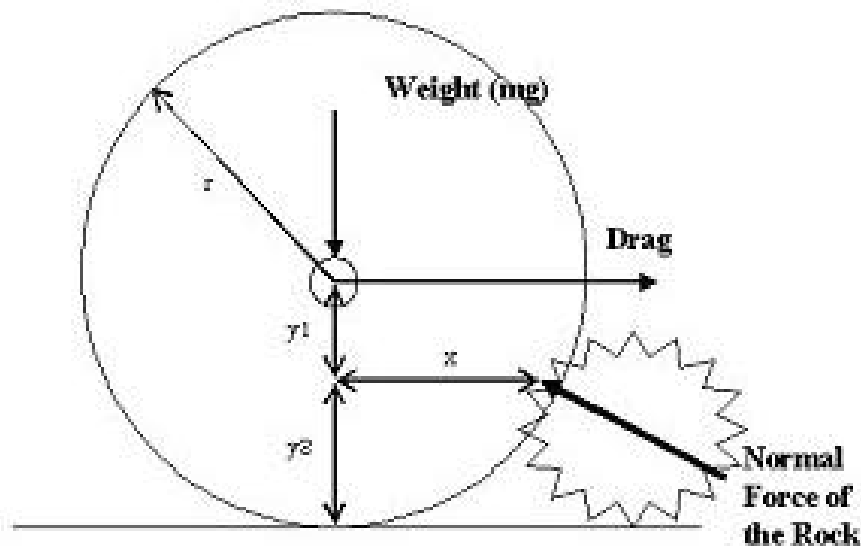
Mars Tumbleweed Mission Sequence: Operation

- Wind-gusts provide mobility
- Data acquisition during mobile and stationary modes of operation
- Data storage and transmission to orbiting Mars assets





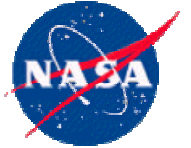
Mars Tumbleweed Rolling Dynamics Theoretical Modeling



- The tumbleweed will roll over a rock when the moment about the rock is positive.
- At that moment, there is no longer a normal force acting from the ground.
- The amount that Tumbleweed will deform is negligible compared with its diameter
- Drag coefficient of tumbleweed is 1.06, based on wind tunnel data obtained during the Downselect Phase.

Mars Tumbleweed

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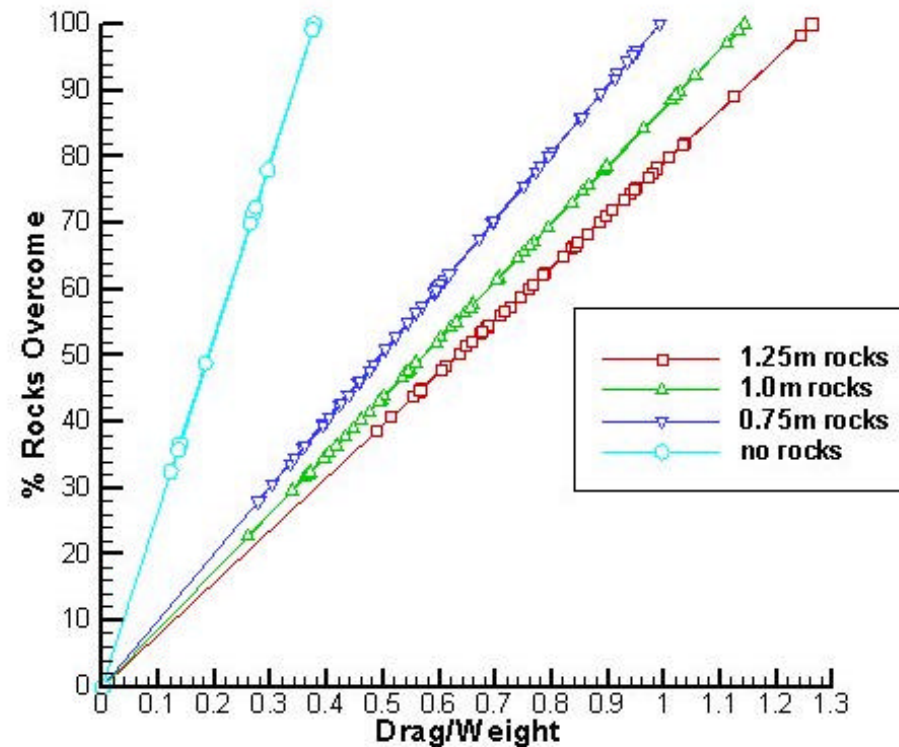
Mars Tumbleweed Rolling Dynamics Empirical Testing



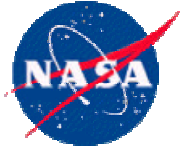
Mars Tumbleweed



Mars Tumbleweed Rolling Dynamics Empirical Testing



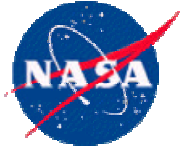
Mars Tumbleweed



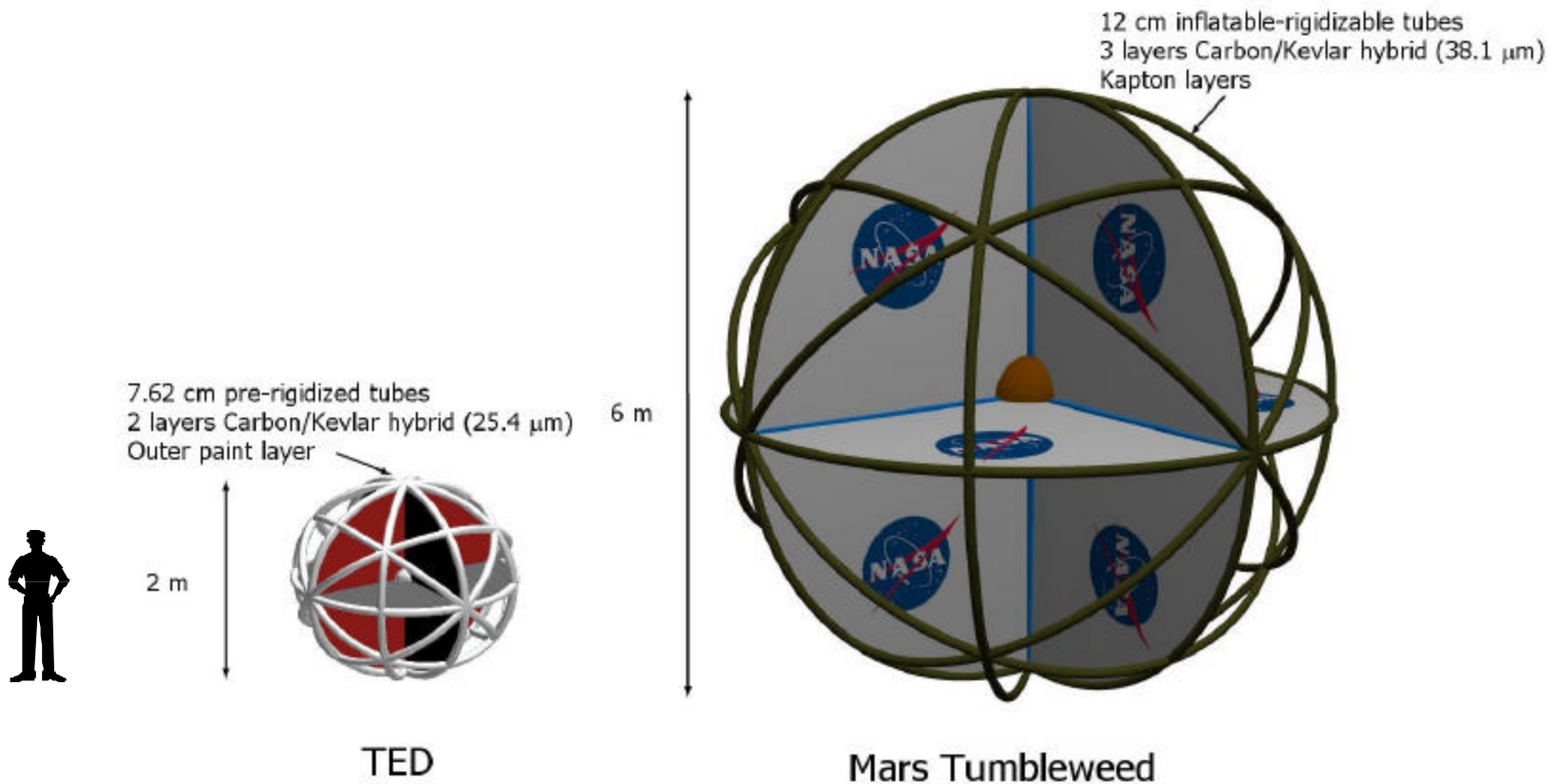
Expected Behavior of Mars Tumbleweed

	Mars	Earth
Drag/Weight	0.244	0.244
Drag coefficient	1.05	1.05
Wind Speed (m/s)	11.77	4
Atmospheric Density (kg/m³)	0.0199	1.17
Accel. Due to Grav. (m/s²)	3.69	9.81
Calculated drag (N)	40.92	25.82
Calculated weight (N)	167.71	105.80

Mars Tumbleweed



TED Compared with Mars Tumbleweed





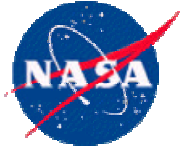
Structural Analysis of the Outer Rings

Assumptions

- Impact @ V_{terminal}
- Impact @ Weakest Point
- 5% Bounce (10cm)
- $V_{\text{terminal}} = 8 \text{ m/s}$
- $F = 15 \text{ kN}$

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Instrumentation on TED

Accelerometers

- ▶ Measures acceleration of TED in all three axes

Environmental sensors

- ▶ Internal pressure transducer to measure local atmospheric pressure
- ▶ Temperature transducer to measure local atmospheric temperature.

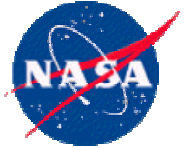
Imager

- ▶ Test the feasibility of surface imaging from a randomly oriented science platform like Tumbleweed

GPS tracking device

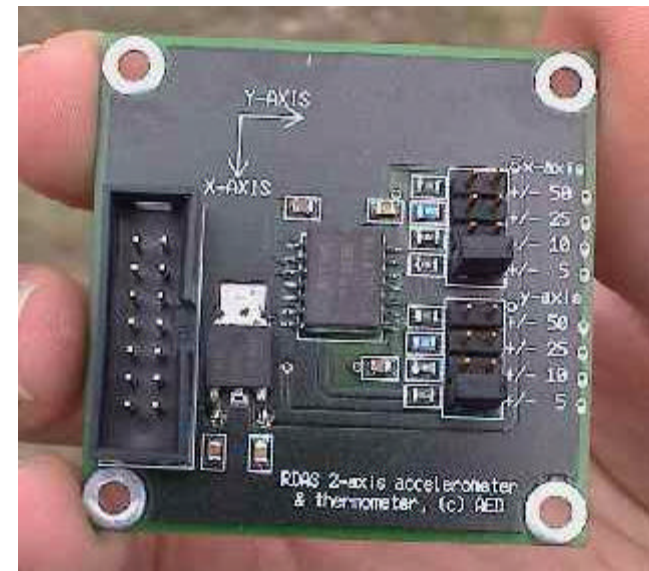
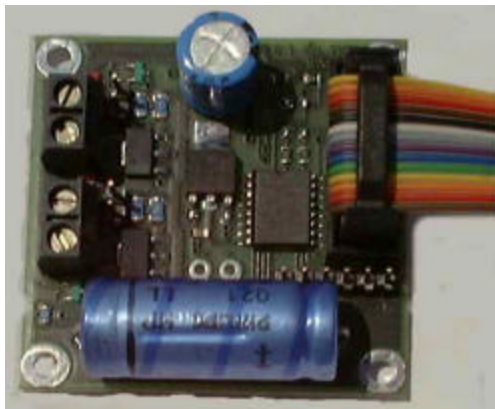
- ▶ Collects position and velocity history in field testing.

Mars Tumbleweed



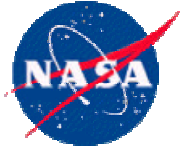
Instrument Subsystems

- Temperature Sensor, Pressure Sensor, Unidirectional Accelerometer built into R-DAS
- B&W Imager
- Biaxial Accelerometer

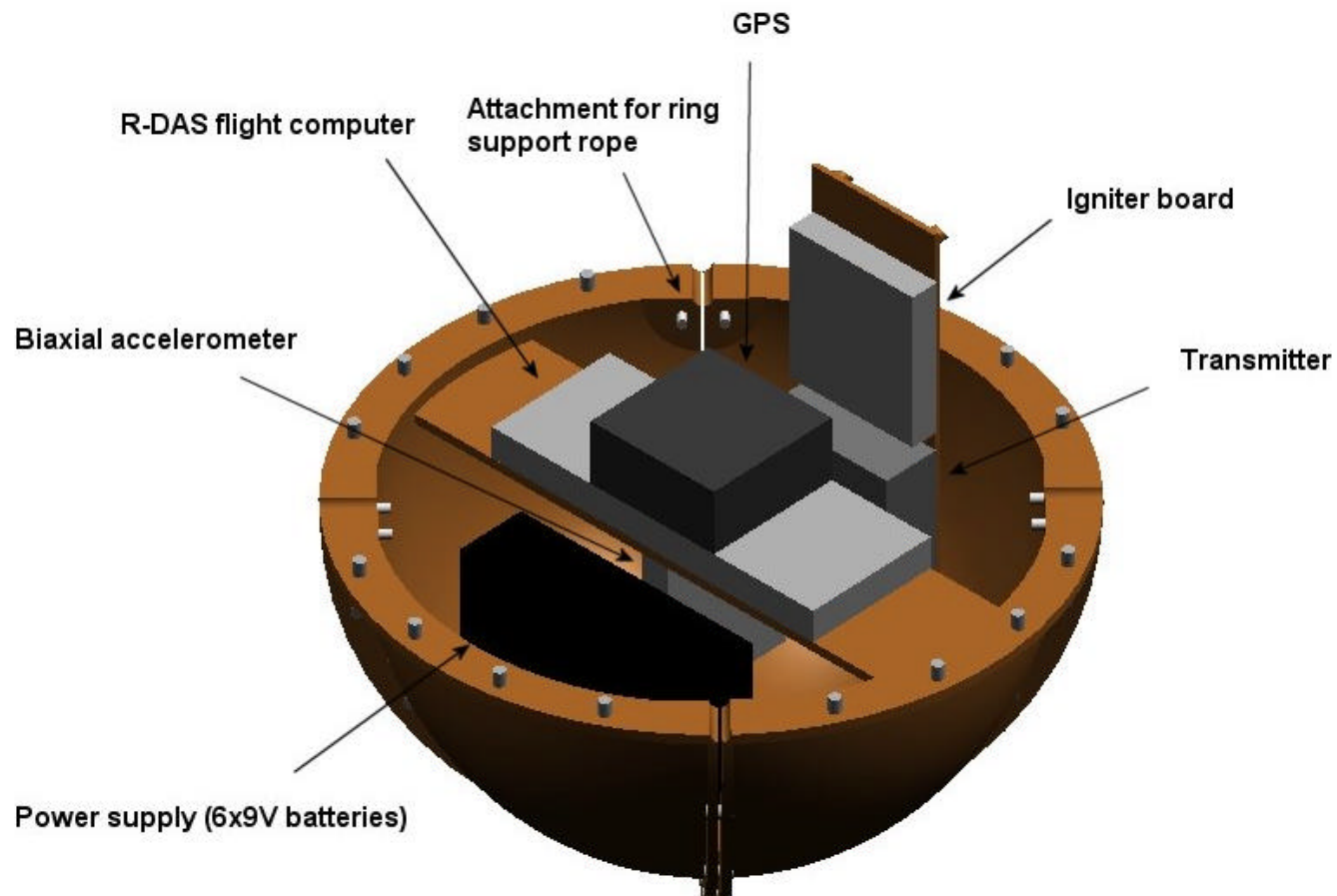


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Instrument Positioning



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Manufacturing



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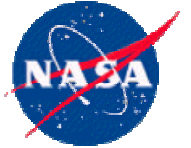


Operations Testing

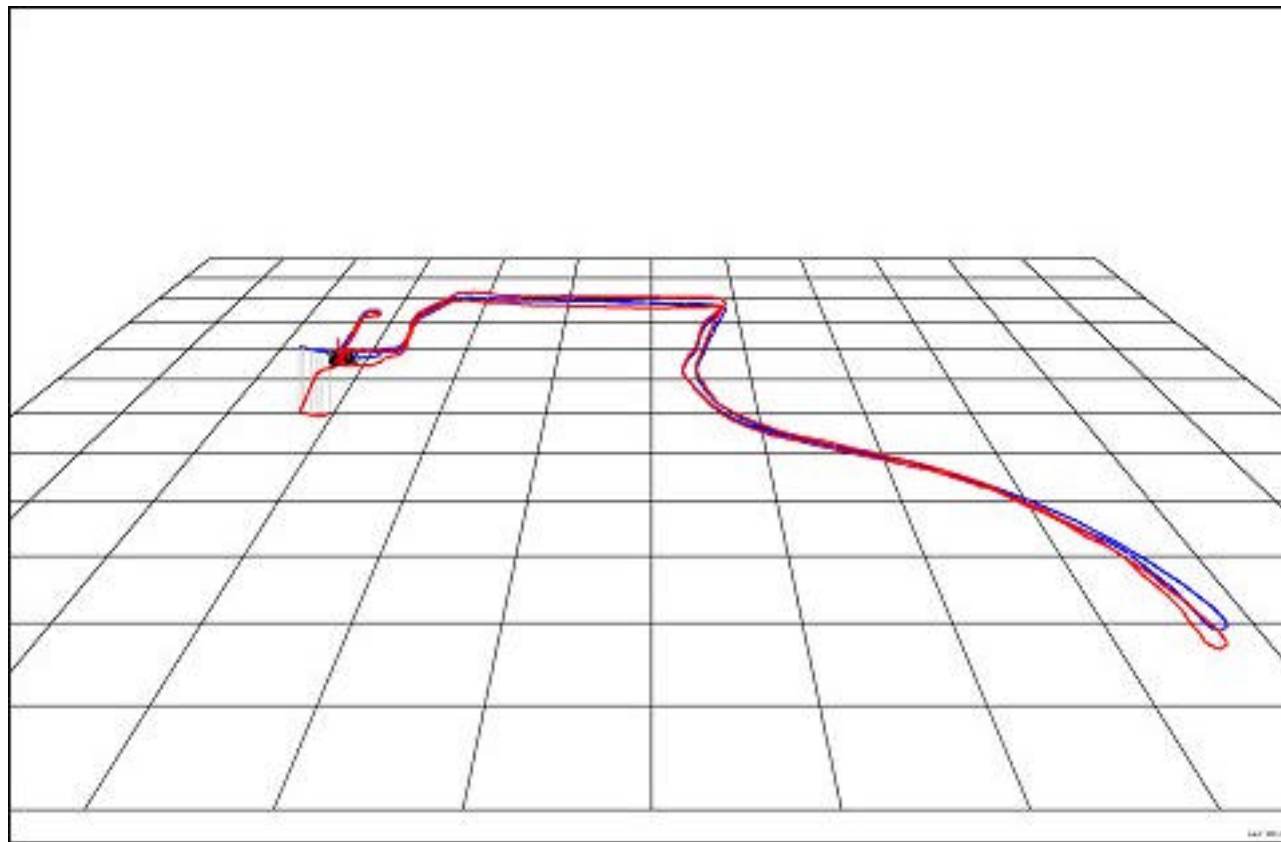
- Field test instrumentation
- Position and velocity histories for dynamics modeling
- Impact history
- Is an imager compatible with the Tumbleweed concept?

Mars Tumbleweed

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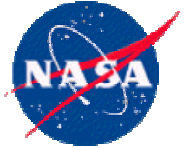


Operations Testing – GPS output

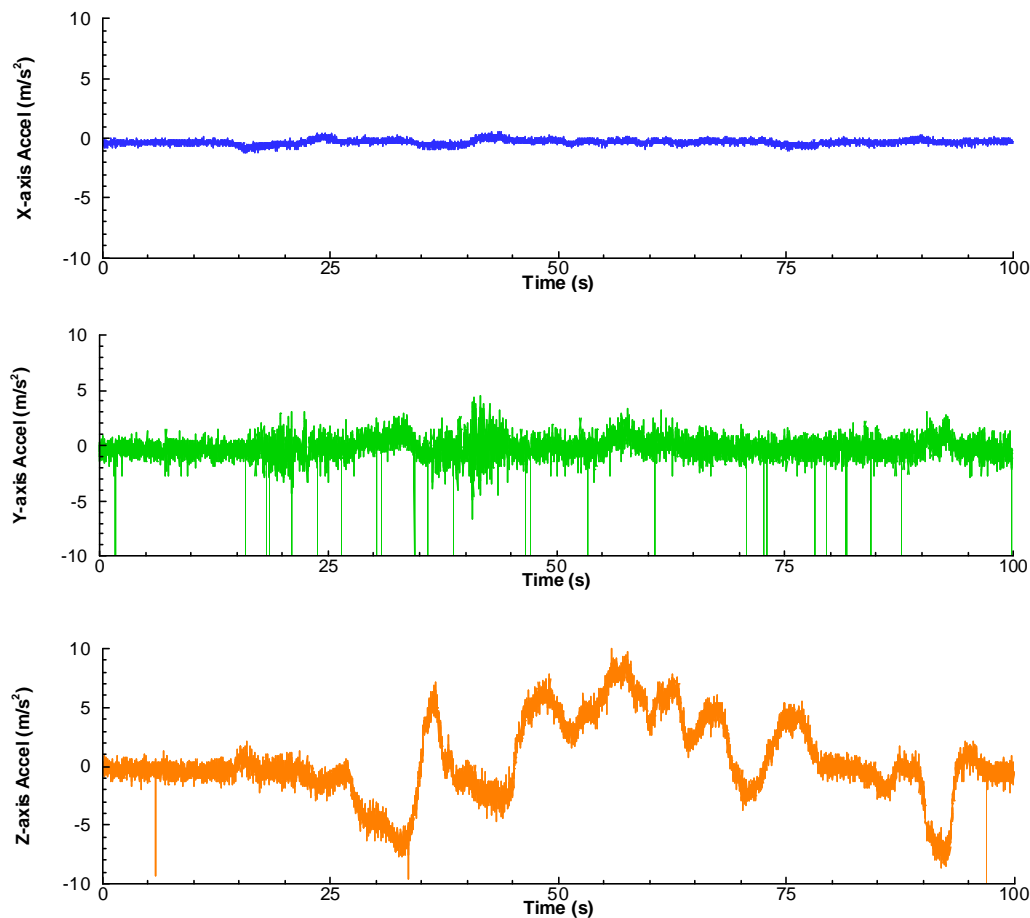


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Operations Testing – 3-axis accelerometer output



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Future of the NCSU Mars Tumbleweed project

- 🌐 Locate a local windy test area and continue operations testing
- 🌐 Take TED to the Mars Society's Mars Desert Research Station (MDRS) in Utah.
- 🌐 Refine dynamic behavior, ie. Determine the "stuckness" factors

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Questions?

